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THE DEEP SEA*

BY

SIR JOHN MURRAY, K.C.B., F.R.S., &c.

When the great *Challenger* Expedition returned to this country in 1876, after having spent three years in the exploration of the great ocean basins in all parts of the world, the one result that riveted the attention of the public was the discovery that living organisms were to be found everywhere in the ocean from the surface waters down to depths of three or four geographical miles. Men were indeed surprised to learn that large and delicate organisms belonging to nearly all marine groups could flourish in these great depths, where the pressure was over four or five tons to the square inch, where sunlight never penetrated, and where the temperature approached the freezing point. Some of these new and strange animals were reminiscent of forms hitherto known only in the fossil condition, and some of them exhibited novel and interesting adaptations to the extraordinary conditions of their environment. Fishes of frail fantastic form were in a pitiable condition when drawn up to the surface. The gases within their bodies had expanded owing to the gradual diminution of pressure, and as a consequence their eyes were blown out of their heads and their stomachs out of their mouths. It was also found that very many of these organisms had the power of emitting a pale blue phosphorescent light from special and peculiar organs—after the manner of searchlights—and of thus illuminating the otherwise eternal darkness.

The floor of the deep sea was shown to be carpeted in places by oozes composed of calcareous and siliceous shells—the houses of pelagic creatures built and tenanted in the surface waters and fallen to the bottom on the death of the tenants—or the bottom was covered with red clay, mixed up in which were hundreds of sharks' teeth and bones of whales, some of them belonging to extinct species, as well as zeolitic crystals, manganese nodules, and metallic particles and chondrites of extraterrestrial origin—the tails of meteorites, in short. Lastly, it has been found that these deep-sea deposits con-

* Sir John Murray gave a lecture with the above title, before the Royal Scottish Geographical Society, in Edinburgh, on Nov. 11, 1910. By the courtesy of the *Scottish Geographical Magazine*, the larger part of the summary of his lecture, which appeared in that periodical (Vol. XXVI, No. 12) is here reproduced.

tain more radioactive matter than any of the continental rocks; in one inch of red clay there is more radium than in the whole overlying layers of sea-water four miles in depth. Scientific men had evidently invaded a new and weird field of research, attractive in a surprising degree to all who take an interest in the advance of natural knowledge. The modern science of oceanography was practically founded by the *Challenger* Expedition and has since been extended by expeditions sent out by nearly all civilized countries, by private expeditions, like those of the late Professor Alexander Agassiz and the Prince of Monaco, by Arctic and Antarctic expeditions, by telegraph ships, by the work of marine laboratories, and especially by the International Fishery Investigations in the North Sea. The physical and biological conditions of the deep sea are now known in their broad general outlines. Let us briefly glance at these conditions.

Thousands of soundings recorded from all parts of the ocean show that the sea-floor may be regarded as vast undulating plains submerged on the average about two and a half miles beneath the surface of the waves, interrupted here and there by submarine ridges and cones, some projecting above the surface as coral and volcanic islands. The greatest depth known is in the *Challenger* (or Nero) Deep in the North Pacific, viz., 5,269 fathoms, or 31,614 feet, in which our highest mountain, Mount Everest, might be placed and yet be covered by 2,600 feet of water. The greatest depth in the Atlantic is 4,662 fathoms, in the Nares Deep, north of the Virgin Islands. The greatest depth in the Indian Ocean is 3,828 fathoms in the Wharton deep, south of Java. The term "deep" is applied to those areas of the sea-floor where the depth exceeds 3,000 fathoms or three geographical miles. Fifty-six such deeps are now known including ten areas where the depth exceeds 4,000 fathoms, and four areas where the depth exceeds 5,000 fathoms, or five geographical miles.

The *salinity* of the sea is highest where drying winds blow over the surface as in the Trade-wind regions, the Red Sea and the Mediterranean, decreasing towards the poles and in the deep sea. But although the amount of salt in solution varies from place to place, and at different times of the year, the composition of sea-salts remains nearly uniform, only slight variations having been detected along continental shores, in polar regions, and in the water intimately associated with deep-sea deposits.

The *temperature* of the sea varies at the surface from 28° Fahr. towards the poles to over 80° Fahr. towards the equator. The an-

nual range of temperature is small—less than 10° Fahr.—in the polar regions, where the actual temperature is low and also in the tropical regions, where the actual temperature is high, and between these areas of small range lie two zones of wide range. This large range of surface temperature is most pronounced in those regions where there is an alternation of warm and cold currents with change of season, resulting in an enormous mortality among organisms living in the surface waters. As examples of such regions of large range may be mentioned the Atlantic coasts of North America and off the Cape of Good Hope. In these localities there is an extra large supply of dead organic matter falling to the bottom and here the greatest hauls of deep-sea animals are taken in the trawls and dredges. Here also the deposits are characterized by the formation of glauconitic and phosphatic nodules.

Beneath the surface, the temperature of the ocean-water rapidly decreases in the tropical regions—the warm surface water forming a relatively very thin film,—so that the great mass of the ocean consists of cold water, usually under 40° Fahr. in all depths greater than 1,000 or 1,500 fathoms. The deposit brought up by the dredge from deep water under the equator, with a broiling sun overhead, is so cold that the hand cannot be placed in it without great discomfort.

The *atmospheric gases*, oxygen and nitrogen, are absorbed at the surface of the sea to a greater extent in cold than in warm regions, and are then carried down to the deepest parts of the ocean by the general circulation kept up by the action of the prevailing winds of the globe. Oxygen is required by marine animals and therefore is used up as it passes down to and over the bottom in the greatest depths, while the nitrogen is unaffected. There is no deficiency of oxygen anywhere in the open ocean where a general circulation is maintained, but in basins cut off from this circulation by submarine barriers, like the Mediterranean, there may be great deficiency, and in the Black Sea there is not enough to support life in the deeper layers of water.

The ultimate *source of the food* of all marine animals is the plant life along the shores and especially in the surface waters of the ocean, where, under the influence of sunlight and chlorophyll, organic compounds are elaborated from inorganic compounds. The surface of the sea down to several hundreds of feet is crowded with myriads of minute unicellular algæ, forming vast floating meadows. The actual amount of vegetable life at the surface of the sea is probably much greater—although so inconspicuous—than that which

clothes the land surfaces. Not only are these floating meadows the feeding-grounds of surface animals, but when their dead remains fall to the bottom they supply food to the mud-eating animals which crawl over the ocean-floor, and these in their turn are eaten by predatory deep-sea creatures. Nowhere in the ocean does there seem to be an absence of life, but the regions of the very deep sea far removed from land may be called deserts when compared with the teeming life of the surface and shore waters.

Such then may be regarded as a general summary of our knowledge of the deep sea at the present time. The work of the *Challenger* Expedition over a quarter of a century ago has been confirmed and extended in many directions, but no very striking or entirely novel discoveries have been made by subsequent expeditions, and the enthusiasm for deep-sea explorations appears to have died away in quite recent years.

Let us now consider the circumstances which led to the *Michael Sars* Expedition during the present year. When Wyville Thomson and Carpenter investigated the Faroe Channel to the north of Scotland in the earliest deep-sea expeditions, they met with temperatures at three-quarters of a mile in depth varying as much as 15° Fahr. in a relatively short horizontal distance, 30° Fahr. in one place and 45° Fahr. in another. Now the *Challenger* investigations in all parts of the world seemed to render it highly improbable that two such bodies of water could exist alongside of each other without an intervening rocky barrier. In consequence the *Knight Errant* and the *Triton* Expeditions were sent out to reinvestigate this area, and a barrier reaching up to within 250 fathoms of the surface was discovered separating the cold Arctic water from the warm water of the Atlantic; not only so; but the faunæ trawled from either side of this range were found to be quite different, only a few of the 500 species captured being common to the two areas.

During the past ten years the Norwegians have been doing a great deal of work in the Norwegian Seas and have brought together great collections from deep and shallow water. It seemed desirable to have collections from different depths along the coasts of the British Isles, Europe, and Africa for comparison with those from the far north. Instruments and methods of deep-sea research have also been much improved within the last ten years. It was desirable to try these in the deep water areas of the North Atlantic, and to explore in a special manner the intermediate waters of the open ocean with modern appliances. Besides, it seemed as if the time had arrived to attempt not so much the capture and descrip-

tion of the new species as to find out the interdependence of oceanic phenomena and their bearing on the wide general physiological and economic problems of the ocean.

In November last year I offered through my friend, Dr. Hjort, to pay all the expenses of a four months' cruise in the Atlantic if the Norwegian Government would grant the use of their fishery boat the *Michael Sars*, for these purposes. The reply was favorable. The *Michael Sars* was a rather small ship for Atlantic work, being only 125 feet in length; on the other hand, she had a trained captain and crew, and the scientific staff was accustomed to taking observations even in very rough weather.

The instruments used in deep-sea work are all of special construction. Moreover, they are all removed from direct observation when at work, and it is not known until they again reach the surface whether they have properly functioned. Their proper working is therefore a source of much anxiety to the practical oceanographer. A thermometer must be reversed by a messenger at the depth at which the temperature is desired; a water-bottle must in like manner be reversed and closed at the depth from which a sample of water is required, and so on in other operations.

The ship proceeded along the coasts of Europe as far south as the Cape Verde Islands, making special observations in the Straits of Gibraltar on the way. She then proceeded to the Sargasso Sea and back to the Azores, afterwards crossing the Atlantic to St. John's, Newfoundland, and returned to Scotland, following the course of the Gulf Stream or North Atlantic Drift. The improved apparatus now in use allowed a very large number of temperature and salinity observations to be taken as well as other physical and biological observations. These details and results will be published as soon as possible.

By using a large otter trawl in the greatest depths it was hoped that large new fishes and cuttle-fishes might be captured which had hitherto escaped. This hope was not realized; but still the trawl was worked successfully down to a depth of three miles, and abundant collections were secured for future study. The fish-fauna in the coastal waters extending from the Norwegian Sea to the coast of Africa at the Canaries varied with the latitude and temperature, but along the continental slopes, between 500 and 1,000 fathoms, the same species of fishes were found over this long stretch.

Professor Helland Hansen, by means of an ingenious apparatus which could be opened and closed at any desired depth, made some interesting observations as to the distance to which the sun's rays

penetrate sea water. At 50 fathoms, during bright sunshine and after an exposure of two hours, all colors of light were found to be present, though many of the red and green rays were cut off. At 300 fathoms red and green rays could not be detected; some blue rays were present, but the light consisted principally of ultra-violet rays. At 500 fathoms some light was still detected, but at 900 fathoms, *i. e.*: about one mile of depth, the photographic plates were unaffected even after long exposure.

The *Michael Sars* sailed specially prepared to examine the fauna and flora of the open ocean down to and beyond the distance to which sunlight penetrates, and in this the expedition has been, in my opinion, a marked success. Various sizes and kinds of nets and trawls were used in the intermediate waters, some hauled horizontally, some vertically, and a great many animals were captured between 300 and 1,000 fathoms which were formerly believed to live near the bottom, such as black fishes and large red crustaceans. Occasionally as many as twelve nets were drawn along at different depths, and the results were compared with those obtained by vertical nets at the same place. These results were interesting when considered in connection with the light observations. The black and red animals captured in 300 fathoms would be invisible when viewed from the surface layers; on the other hand, the crystal-clear and blue animals which float on the surface would be invisible when viewed from the deeper layers.

Great attention was paid during the whole cruise to the young fishes and fish-larvæ found floating in the surface and sub-surface waters. This expedition was undertaken—at all events so far as I am concerned—simply with the view of increasing natural knowledge, but one can never tell when one may stumble across results of economic importance. Let me give an example. You all know that the salmon enters freshwater rivers from the sea for spawning purposes, and afterwards returns to the ocean. With the common eel it is the reverse; it lives in the fresh water and descends to the ocean to spawn, the young returning to the rivers and lakes as elvers. Now, in recent years it has been shown that the larvæ of eels are small transparent fishes known as *Leptocephali*. These are continually found in the tow-nets, but the very young stages and the ova of the eels have never been found in the ocean and the geographical position of the spawning grounds is as yet unknown. Now, along the continental slopes, and in the North Atlantic north of the Azores, we found full-grown *Leptocephali* and transformation stages, as Dr. Schmidt and others had done before us, but to the south of the

Azores we found that all the eel-larvæ were younger than any hitherto captured, and although the ova have not—so far as the examination has proceeded—been found, still our observations point, according to some of my colleagues, to the spawning area of the common eel being situated somewhere in the southern part of the North Atlantic, probably between the Canaries and Bermuda. This observation may in the not distant future have a direct bearing on economic fishery questions.

The day before the ship sailed from England a large centrifuge was purchased and fixed to the deck to be driven by a steam winch. Water was collected from different depths in the ocean by means of the water bottle, and placed in the centrifuge, which was then rotated. In this way all the minute organisms in the sea-water were collected in the bottom of the rotating tubes, and could be examined under the microscope and counted. Professor Gran found that vast numbers of unicellular plants were present in all the surface layers of the ocean—especially the *Coccolithophoridae*. As these all escape through the meshes of the finest silk used by the German Plankton Expedition, it seems certain that the general results of that expedition will require to be very considerably amended.

The samples of deep sea deposits obtained during the cruise confirm previous observations, but the stones brought up by the trawl over the area are of exceptional interest. These are being examined by Dr. Peach, and he reports that fully 20 per cent. are glaciated fragments. They consist of granite, gneiss, shales, sandstones, chalks, limestones, and flints, and some of these contain fossil remains. The condition of these fragments shows that in many instances they projected above the surface of the deposit in which they were imbedded. Dr. Peach has no doubt that these stones were carried by ice during the later phases of the glacial period to the position in which they were found. They almost all belong to the series of sedimentary, metamorphosed, and erupted rocks now found *in situ* in this country and in Ireland. But the interesting question is: Why have these fragments not been completely covered up by the shells which are continually falling from the surface? Telegraph engineers give reasons for believing that in some localities and depths the rate of accumulation is at least one inch in ten years; at this rate all rock-fragments deposited during the glacial period should have been buried in the ooze far beyond the reach of the trawl. Most probably the tidal currents, which our observations showed to exist in deep water, extend right down to the bottom and remove the

small *Globigerina* shells from any ridges. Still, there may be other explanations of the facts.

Mixed up with these stones is a remarkably large number of cinders from steamers. If steamers using coal should some day be superseded by vessels using some other kind of fuel, then the deposits in the North Atlantic would have a layer which might be called the coal-fuel layer. On the other hand, if the coal-cinders and these glaciated rock-fragments are now lying together on the floor of the ocean, geologists may in the remote future find proofs in these layers that man and steamers existed in the glacial period.

I have referred to only a few of the results and observations taken during this four months' cruise. When published in detail these will form a substantial addition to knowledge, and it is in my opinion almost certain that they will lead to other and more extensive explorations of the same nature in the immediate future.

MACQUARIE ISLAND AND ITS ROBINSON CRUSOE

The chief results of the voyage of Capt. J. K. Davis, on the *Nimrod* (May-July, 1909), under instructions from Lieut. Shackleton to try to locate certain islands in the South Pacific, shown on the charts, were reported in the *Bulletin* (Nov. 1910, p. 852). His full report on this voyage appears in the *Geographical Journal*, (Vol. 36, pp. 696-703). From this account is reproduced here Capt. Davis's description of Macquarie Island, and the solitary white inhabitant he found there. He says:

"About 545 miles from the southern extremity of New Zealand lies Macquarie Island. Capt. Hasselborough, of the brig *Perseverance*, landed there in 1809, but as he saw the remains of a wreck on the coast, it may have been visited by some navigator at an earlier date. Lying as it does in a north-east and south-west direction for a length of over 20 miles, it forms a huge breakwater exposed to the full force of the prevailing westerly winds. It is a mountain ridge rising from a considerable depth. We found a depth of 300 fathoms about half a mile from the eastern shore, shoaling rapidly as we approached the land to 40, 10, 8 fathoms. The southeast side is, for some miles, a precipitous cliff about 200 feet high, broken here and there by watercourses coming down from the plateau behind.